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Research Letter

A new estimate of carbon for Bangladesh forest ecosystems with their spatial distribution and REDD+ implications

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ABSTRACT

In tropical developing countries, reducing emissions from deforestation and forest degradation (REDD+) is becoming an important mechanism for conserving forests and protecting biodiversity. A key prerequisite for any successful REDD+ project, however, is obtaining baseline estimates of carbon in forest ecosystems. Using available published data, we provide here a new and more reliable estimate of carbon in Bangladesh forest ecosystems, along with their geo-spatial distribution. Our study reveals great variability in carbon density in different forests and higher carbon stock in the mangrove ecosystems, followed by in hill forests and in inland Sal (*Shorea robusta*) forests in the country. Due to its coverage, degraded nature, and diverse stakeholder engagement, the hill forests of Bangladesh can be used to obtain maximum REDD+ benefits. Further research on carbon and biodiversity in under-represented forest ecosystems using a commonly accepted protocol is essential for the establishment of successful REDD+ projects and for the protection of the country's degraded forests and for addressing declining levels of biodiversity.

Key words: carbon budget, forest conservation, forest ecosystem, REDD+, Bangladesh.

Introduction

Globally, about 60% of the carbon is stored in forests, with about 12-20% of anthropogenic greenhouse gas (GHG) emissions being attributable to forest degradation and loss (Baccini et al. 2012; Houghton et al., 2012; Paoli et al. 2010; Clark et al. 2001). In the tropical region, reducing emissions from deforestation and forest degradation (REDD+) is a new climate change mitigation mechanism that aims to promote carbon sequestration by compensating tropical countries for conserving their forests (Angelsen et al. 2009; Parker et al. 2009). REDD+, in

Highlights

- We estimate 251.8 million Mg of carbon stored in Bangladesh forest ecosystems, with nearly 49.4% stored in the mangrove forests alone;
- We find 179.1 million Mg Carbon in forest biomass and 72.7 million Mg carbon in soil;
- The hill forests have the highest potential for forest carbon enhancement and REDD+ in the country.

recent years, has been increasingly recognized for its potential to jointly address the issue of climate change mitigation and forest conservation in the tropics (Phelps et al. 2012). Since 2009, REDD+ programs have generated estimated carbon investments of about US$2 billion worldwide (Budiharta et al. 2014; Peters-Stanley et al. 2013). The successful implementation of REDD+ projects, however, relies largely on the robust estimation of carbon stored in forest ecosystems, with demonstrated benefits to local biodiversity and people (Saatchi et al. 2011; Paoli et al. 2010).

REDD+ programs require participating countries to quantify GHG emissions and removals from forests in a manner that is reliable, transparent, and as accurate as possible (Phelps et al. 2012; Gibbs et al. 2007). In many countries, however, large uncertainties still remain surrounding the emission estimates that arise from inadequate data on carbon density in local forests and unreliable estimates of national deforestation rates (Baccini et al. 2012). Unfavorable policy environments and technical challenges of measuring, reporting, and verifying GHG emissions from forests also remain critical in many developing countries (Harris et al. 2012; Baker et al. 2010). Developing countries that wish to participate in REDD+ programs need to construct a reference emissions level, which can be used as a benchmark for estimating emission reductions to be achieved by local REDD+ projects (Harris et al. 2012). National-level distribution of carbon in aboveground forest biomass and soil based on improved data sets can be very useful and act as initial steps for successful REDD+ projects (Alamgir and Turton 2014; Mukul 2014; Shin et al. 2008). A national forest monitoring system and standardized protocols for measuring GHG emissions from forests are also important for the implementation of REDD+ projects in tropical developing countries (Blom et al. 2010; Angelsen et al. 2009).

Here, we provide a new estimate of carbon in Bangladesh forest ecosystems based on published literature. We compile and review related studies that report carbon stocks in biomass and soil in Bangladesh forest ecosystems. In doing so, we first provide relevant information on land use and forests in Bangladesh within the broader context of climate change. We then categorize the forests into three major categories (i.e. evergreen to semi-evergreen hill forests, littoral mangrove forests, and deciduous Sal forests) based on vegetation and ecology, and estimated carbon in biomass and soil for each category, with relevant maps showing their geo-spatial distribution. We believe our study is an initial step to recognize the role played by Bangladesh forests in climate change mitigation. Our study uses scientifically rigorous, reliable, and locally available forest inventories and will be useful for the advancement of national REDD+ programs and forest-based climate change mitigation project developments.

Land-use, land use change and forestry (LULUCF) in Bangladesh

Agriculture is the main land-use in Bangladesh, comprising nearly 65% of the country's land area, followed by forests (17.5%), urban/built-up areas (7.9%), and water (Figure 1; Dey et al. 2012). Forests occupy about 2.53 million hectares in Bangladesh (Khan et al. 2007). Of these, 1.53 million hectares (10.53% of the country's total land) are under the jurisdiction of the Forest Department (FD) (Alamgir and Turton 2014; Table 1). The remaining areas are unclassed state forests (0.73 million hectares) under the control of district administration and homestead forests (0.27 million hectares) owned by smallholder landowners (Khan et al. 2007). Most of the forests in the country are regenerated secondary forests (53%), followed by primary (30%) and planted (17%) forests (Mongabay 2014).

Bangladesh lost about 2.8% (~58,000 ha) of its forest coverage between 2000 and 2012 (Hansen et al. 2014, 2013), and still has one of the highest rates of deforestation in Asia (Poffenberger 2000). Most of

Table 1. Forest lands under the Forest Department's control in Bangladesh

Forest type	Area (million hectare)	Percentage (%)	
		# country's forest area	# country's land area
Hill forests	0.67	44.1	4.5
Mangrove forests	0.60	39.6	4.1
Mangrove plantation	0.13	8.5	0.9
Sal forests	0.12	7. 9	0.8
Total	1.52	100	10.3

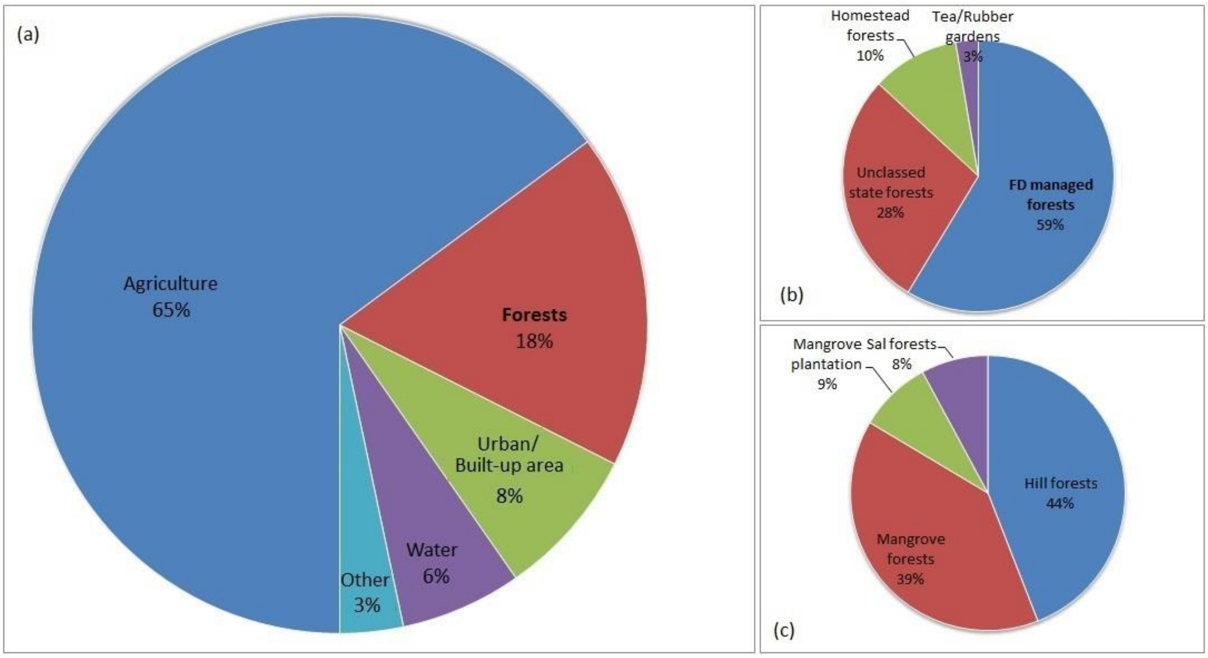

Figure 1. (a) Major land-use/land cover in Bangladesh, (b) tree-based land-use/land cover, and (c) major forest types managed by the Forest Department.

the country's state-owned forests are degraded in nature (Biswas and Choudhury 2007). Rural people's dependence on forests and diverse stakeholder engagement make forest management in the country very complex and challenging (Rashid et al. 2013; Mukul et al. 2012).

The highly diverse hill forests are situated mainly in the Chittagong and Sylhet division and are evergreen to semi-evergreen in nature (Khan et al. 2007; Figure 2, a, b). The Sundarban mangrove forest is the world's largest contiguous mangrove forest and is situated in the Khulna district (Figure 2, c). It is dominated by Sundri (*Heritiera fomes*) and is renowned for being the home of the globally endangered Bengal tiger. The mangrove plantations (Figure 2, d) are located on the newly accreted islands of coastal Bangladesh and are dominated mainly by Keora (*Sonneratia apetala*). The deciduous Sal forests (Figure 2, e) are located on relatively plain lands in the central districts of Bangladesh and are dominated mainly by Sal (*Shorea robusta*). Although managed by smallholders and rural landowners, the homestead forests represent one the most productive systems in Bangladesh (Kabir and Webb 2008; Figure 2, f).

Forestry in the context of climate change mitigation in Bangladesh

About 20% of Bangladesh's GHG emissions are estimated to derive from LULUCF activities, although the contribution of the country to global GHG emissions is rather low, being less than 0.2% (WRI 2014). Per capita CO_2 emissions are also one of the lowest in the world and were estimated at 0.37 metric tons in 2011 (World Bank 2014).

There is no complete inventory for forest carbon estimation in Bangladesh. The latest assessment by the Food and Agriculture Organization of the United Nations (FAO) (i.e. Global Forest Resources Assessment 2010) reports 81 million Mg (Megagram; 10^3 kg) carbon in living forest biomass in the country (FAO 2010). By contrast, Alamgir and Turton (2014) reported carbon density between 49-121 Mg ha^{-1} in the country's forests depending on the condition of the vegetation (e.g. open canopy versus closed canopy). A large variability exists also in the national-level estimates of forests' carbon density, which is mainly attributable to differences in methods and sampling strategies (see Table 2). Using carbon densities reported in the literature, the carbon stocks in FD-managed forests is estimated to be between 98.8 and 240.2 million Mg (Table 2). The estimated carbon storage in soil (up to 30cm depth) in the country's forests is about 92.9 million Mg (FAO 2007, 1977). The highest soil carbon density is in the mangrove forests due to the greatest concentration of organic carbon in soil and is the lowest in the mangrove plantations (see Table 3). The plainland Sal forests, due to their degraded nature, also have relatively lower levels of soil carbon density and stock.

Figure 2. Different forest types in Bangladesh, from top left: (a) hill forest in the Chittagong Hill Tracts, (b) hill forest in Sylhet, (c) mangrove forest in the Sundarbans, (d) a mangrove plantation in coastal Bangladesh, (e) Sal forest in central Bangladesh, and (f) homestead forest in southern Bangladesh (Photo credits: Sharif A. Mukul).

Table 2. National-level estimates of biomass carbon in FD-managed forests in Bangladesh

Source	Carbon density (Mg ha^{-1})*	Carbon stock (Million Mg)	Remark
Saatchi et al. 2011	70.5	107.2	Based on satellite data
Gibbs and Brown 2007	158	240.2	Based on forest inventory
Gibbs et al. 2007	65	98.8	Based on harvest data
IPCC 2006	93	141.4	Based on harvest data
DeFries et al. 2002	137	208. 2	Based on harvest data
Brown 1997	92	139.8	Based on forest inventory
Mean	102.6	155.9	

*using median value when providing a range.

Table 3. Soil carbon storage in different forest types in Bangladesh

Forest type	Carbon density* (Mg ha^{-1})	Carbon stock (Million Mg)	Remark
Hill forests	49. 5	33.2	SOC– 1.5%, and bulk density - 1.1
Mangrove forests	88.2	52.9	SOC – 2.1%, and bulk density - 1.4
Mangrove plantation	19. 6	2.6	SOC – 0.45%, and bulk density - 1.5
Sal forests	34.5	4.2	SOC – 1.0%, and bulk density - 1.15
Total		92.9	-

Sources: FAO (2007, 1977)

Estimate of carbon in Bangladesh forest ecosystems

We estimate 179.1 million Mg carbon in biomass and 72.7 million Mg carbon in soil (up to 30cm depth) in Bangladesh forest ecosystems that are currently under the FD's jurisdiction. These figures, however, may overestimate the actual carbon storage in Bangladesh forest ecosystems, recognizing the fact that many of the country's forests are degraded in nature. Tables 4 and 5 below show the reported carbon density in different forest types in Bangladesh that are used for these estimates. Here, we only consider the studies that are from primary and old growth secondary forests and do not include studies from monoculture, agroforestry, and/or plantation forests. The number of studies on soil organic carbon (n=11) is relatively higher than the studies on biomass carbon (n=7). There are only a few studies on plainland Sal forests and there are no studies on mangrove plantations. The majority of the studies have been conducted in the hill forests of the Chittagong and Chittagong Hill Tracts.

Table 4. Carbon in biomass in different forest types of Bangladesh

Forest type	Carbon density* (Mg ha^{-1})	Source
Hill forests	103.4	Mukul 2014
	115.6	Ullah and Al-Amin 2012
	73.6	Alamgir and Al-Amin 2007
	92.0	Shin et al. 2007
Mangrove forests‡	98.9	Rahman et al. 2014
	126.7	Donato et al. 2011
Sal forests	153.9	Kibria and Saha 2011

*using median value when providing a range.
‡includes mangrove plantations.

Table 5. Soil organic carbon in different forest types of Bangladesh

Forest type	Carbon density* (Mg ha^{-1})	Source
Hill forests	51.0	Mukul 2014
	23.1	Barua and Haque 2013
	50. 5	Ullah and Al-Amin 2012
	54.0	Miah et al. 2009
	80.1	Chowdhury et al. 2007
	97.7	Shin et al. 2007
	39.7	Islam et al. 2001
Mangrove forests‡	33.6	Rahman et al. 2014
	43.9	Donato et al. 2011
Sal forests	58.5	Kibria and Saha 2011
	38.1	Isalm and Weil 2000

*using median value when providing a range.
‡includes mangrove plantations.

The average ecosystem carbon density in Bangladesh forests is estimated at about 175.5 Mg ha^{-1} (Table 6). Despite its degraded nature, we find the highest carbon density in the Sal forests (202.2 Mg ha^{-1}), which could be due to a limited number of studies (n=1) on biomass carbon and bias in sampling. This could be the same case for soil carbon in mangrove forests. Mangrove forests constitute the highest share (54%) of the country's biomass carbon stock, followed by hill forests (36%) and the Sal forests

(Figure 3). Soil organic carbon stock is, however, highest in the hill forests (38.6 million Mg), comprising nearly 53% of the country's total carbon stock in soil (Figure 4). Based on the studies, we find higher uncertainty in soil carbon density in the hill forests (47.1%) followed by the Sal forests (29.9%) and mangrove forests (Figure 5).

Table 6. Carbon density in major forest types in Bangladesh

Forest type	**Carbon density** (Mg ha^{-1})		
	Biomass	Soil	Total
Hill forests	96.1 (±17.86)	57.6 (±27.13)	153.7
Mangrove forests‡	112.8 (±19.66)	38.8 (±7.28)	151.5
Sal forests	153.9 (0)	48.3 (±14.42)	202.2
Mean	120.9	48.2	169.1

‡inlcudes mangrove plantation.

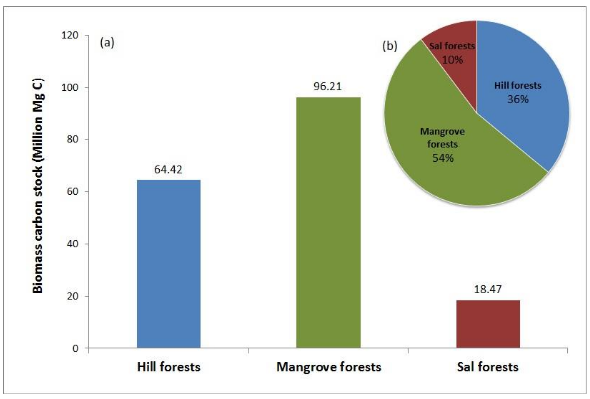

Figure 3. Carbon stock in biomass in major forest types of Bangladesh (a), and their relative contribution (b).

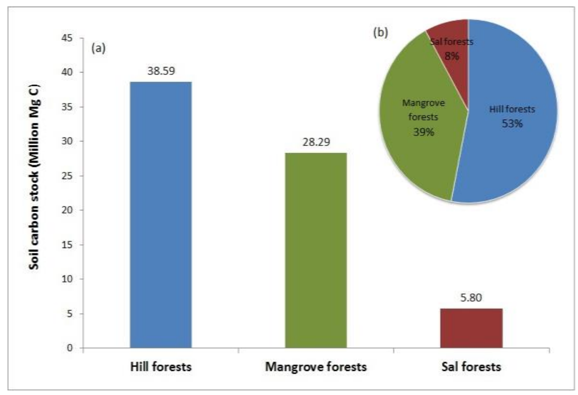

Figure 4. Soil organic carbon storage in major forest types of Bangladesh (a), and their relative contribution (b).

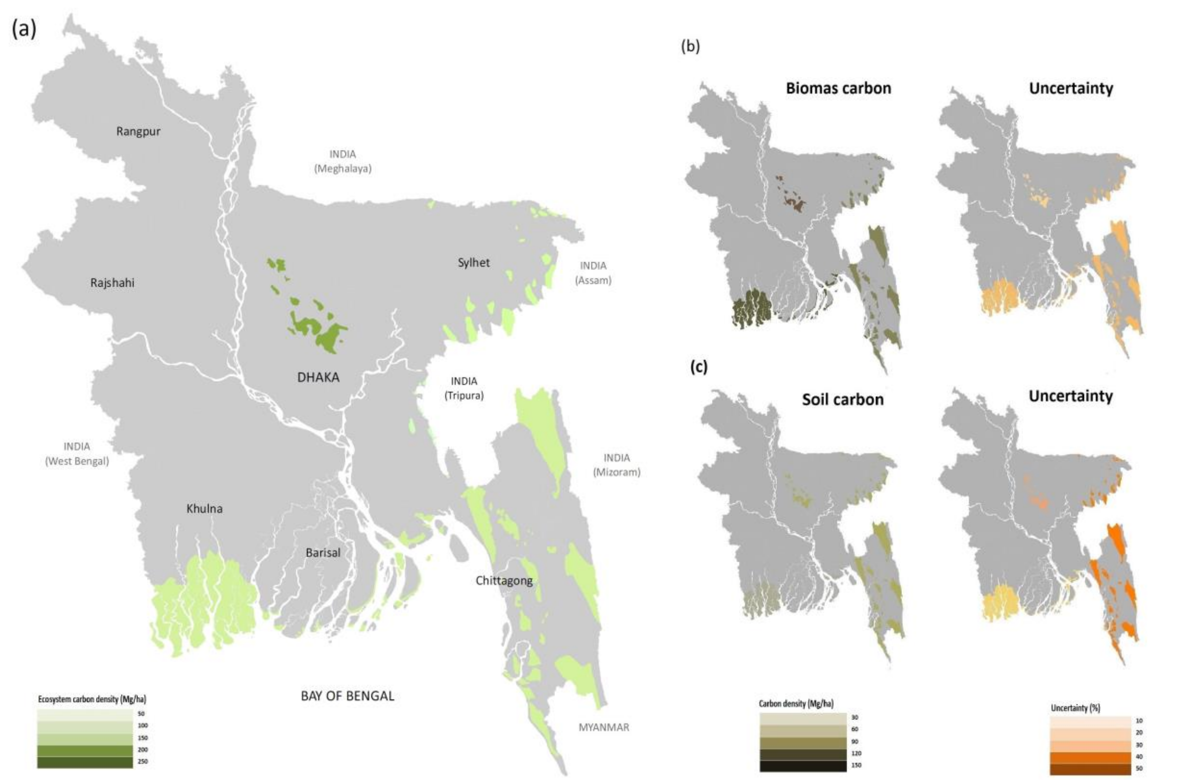

Figure 5. Map showing the density and spatial distribution of carbon in Bangladesh forest ecosystems; (a) total ecosystem carbon, (b) biomass carbon and uncertainty, and (c) soil carbon and uncertainty.

Concluding remarks

Altogether, we find 251.8 million Mg carbon stored in Bangladesh's forest ecosystems, with nearly 49.4% stored in the mangrove forests alone. Our estimate, however, is based on a limited number of available field inventories conducted into Bangladesh forest ecosystems, limiting the reliability of our estimates. Further studies should cover underrepresented forest ecosystems in the country using a commonly accepted protocol and sampling strategy. The mainland Sal forests represent the most degraded ecosystem in the country, while the mangrove forests are relatively intact due to limited human influence (Donato et al. 2011; Rahman et al. 2010). The hill forests located in the Chittagong, Chittagong Hill Tracts, and Sylhet are severely degraded due to illegal logging and shifting cultivation (Mukul et al. 2014; Khan et al. 2007). Local dependence on forests and unsustainable resource collection are also common in the hill forests (Miah et al. 2014).

The spatial distribution of forests is not uniform in the country, scattered mostly in the few districts of southern, central, and coastal Bangladesh (see Figure 5). The quality and quantity of forests has also decreased over the past decades (Biswas and Chowdhury 2007). Although not properly recognized, the potential found in Bangladesh's forests in terms of climate change mitigation through sequestering atmospheric carbon is still undeniable (Rahman and Akter 2013; Brown et al. 1993). To fully utilize this opportunity, the carbon sequestration potential of the country's forests should be integrated with REDD+ and other available carbon payment schemes (Sohel et al. 2009).

Due to diverse stakeholder engagement, coverage and the current state of forests, the hill forests of the country have the highest potential for forest carbon enhancement and REDD+. Tackling deforestation is the cheapest option for reducing human-induced GHG emissions and thereby for addressing climate change (Houghton 2013). Restoration of degraded forests using locally available species is also an ideal strategy for forest carbon enhancement in the country (Miah et al. 2009). Protection of degraded forests to allow natural regeneration, establishment of plantation in barren lands, and avoiding deforestation are some other key strategies that could also aid forest carbon enhancement (Niels et al. 2002). Creation of protected areas in forests with fair and equitable access for local people and their involvement in forest management and governance are also critical (Chowdhrury et al. 2014; Rashid et al. 2013). Understanding rural livelihoods and economic cost-benefits are core to successful forest management in the country (Biswas et al. 2009). To be socially acceptable, the value of unit carbon for REDD+ projects, therefore, should be sufficient to compensate the foregone monetary value associated with changes to local and indigenous people's traditional forest use in Bangladesh.

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